

pRad VISAR: An Interferometer-Based Optical Diagnostic for Proton Radiography

One method to determine the velocity of a moving surface is to measure the Doppler-shifted frequency of light reflected off that surface. A sensitive measurement of frequency can be made with an interferometer. One specific interferometer configuration for such a measurement was developed at SNL and LANL and is called VISAR, for velocity interferometer system for any reflector.^{1,2} We have developed and implemented a VISAR capable of measuring up to seven points simultaneously for the LANL pRad facility. In this article, we briefly describe how our VISAR works and how it is used to supplement proton radiographs.

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How VISAR Works

A VISAR is diagrammed in Figure 1. After reflecting off the surface in question, light enters the interferometer from the fiber-optic input on the left-hand side (LHS) and is incident on a 50/50 beamsplitter. Half the light is reflected off the beamsplitter, the LHS mirror, and is incident on the beamsplitter again. The other half of the light traverses the right-hand side (RHS) of the interferometer. For imaging, the RHS is optically equivalent to the LHS despite having an optically flat element, an etalon, in the beam path. The etalon induces a frequency-dependent phase shift between the light traversing either side of the interferometer. After the light is recombined at the beamsplitter, the relative phase shift is measured by keeping count of the Michelson-type fringes through the fiber-coupled output of the device; the fringes are manifested as modulations in the light intensity. The light frequency can be deduced from this relative phase shift. A single fiber-coupled output would suffice for a measurement, but the eighth-waveplate, output polarizing beamsplitters, and additional outputs allow for greater precision throughout the measurement range and calibration against light-intensity variations and unwanted scattered light.²

In addition to allowing for measurements with reflected light from diffuse surfaces, having each side of the interferometer optically equivalent allows measurements of velocity of different points at the same time. Rather than a single optical fiber for input, a bundle of seven fibers is used (Figure 2).

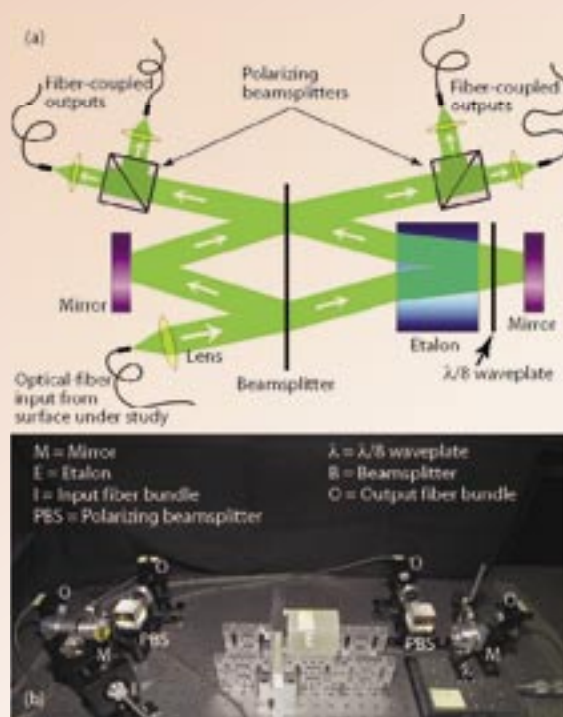


Figure 1. (a) Schematic diagram and (b) photo of the pRad VISAR. Details are given in the text.

Material Studies Research Highlights

Figure 2. Photo of the input fiber bundle on which the ends of the seven individual fibers can be seen. The diameter of the hole for each fiber is $370\text{ }\mu\text{m}$.



Each fiber in the bundle carries light reflected from a different test point on the experiment. The input bundle is carefully imaged onto four identical fiber bundles at the four output arms of the interferometer. The four output intensities of each of the seven test points can then be recorded simultaneously on a streak camera.

The streak camera records data with a $1,000 \times 1,000$ -pixel CCD with 15 ns/pixel, typically. The noise on the velocity measurement is usually below 40 m/s. The breakout time, the time of a sudden change in surface velocity caused by shock, can usually be determined with an instrumental precision of ± 30 ns. In parallel with the streak camera, the light intensities from at least one point can also be recorded with photomultipliers and a digitizing oscilloscope. Typical sample time for the scope is 2 ns.

Integrating VISAR with pRad

The pRad dome (located in Area C at LANSCE) environment presents challenges for setting up a VISAR system. Hazards such as radiation and high explosives are integral to the facility, so the VISAR light source, optics, and data-acquisition equipment must be located outside the pRad dome. Conversely, the VISAR must be operated in such a way that workers are not endangered by its high-power laser.

A schematic overview of how the VISAR equipment is integrated into the pRad area is shown in Figure 3. A separate, interlocked room houses the VISAR equipment and controls. The light for the VISAR comes from a laser producing 10 W at 532 nm. After passing through an attenuator and a fast switch, the laser beam enters a seven-way switchyard, where it can be divided into seven beamlets of arbitrary intensity. Each of the seven beamlets is coupled into a fiber-optic cable that carries the light 100 m to the pRad dome. A vacuum feed-through connects this supply fiber to the VISAR probe. The VISAR probe

is a compact optical device placed in the vacuum chamber with the test object. The probe (Figure 4)

- directs the collimated laser light to the surface of the test object,
- gathers the light that is reflected back, and
- couples it back into a second fiber of the vacuum feed-through.

The output of the probe is returned to the VISAR room, where it is directed into one of the seven interferometer input fibers.

Experimental Results

VISAR surface-velocity measurements and proton radiographs complement each other well. Proton radiographs reveal three-dimensional views of the total volume of an object during a dynamic event but do so at discrete intervals of 3 μs , typically, and the images are integrated over 50 ns. VISAR can only reveal the velocity of the exterior surface of the object but provides a relatively continuous record with measurements every 2–15 ns.

Experiments to study high-explosive-induced damage and spall^{3,4} in selected metals demonstrate how VISAR data can enhance observations of dynamic experiments. These experiments study the behavior of metals when the free surface reflects a Taylor wave generated by high explosives. Figure 5 is a diagram of such experiments performed in conjunction with pRad operations.

Some results of these experiments, showing the velocity of the metal surface as measured by the VISAR, are shown in Figure 6. The terminal velocity, velocity pullback, shock breakout, and ringing period of the surface can be seen in the VISAR data. This information yields independent measurements of parameters such as the spall strength of the material and thickness of the first spall/damage layer.

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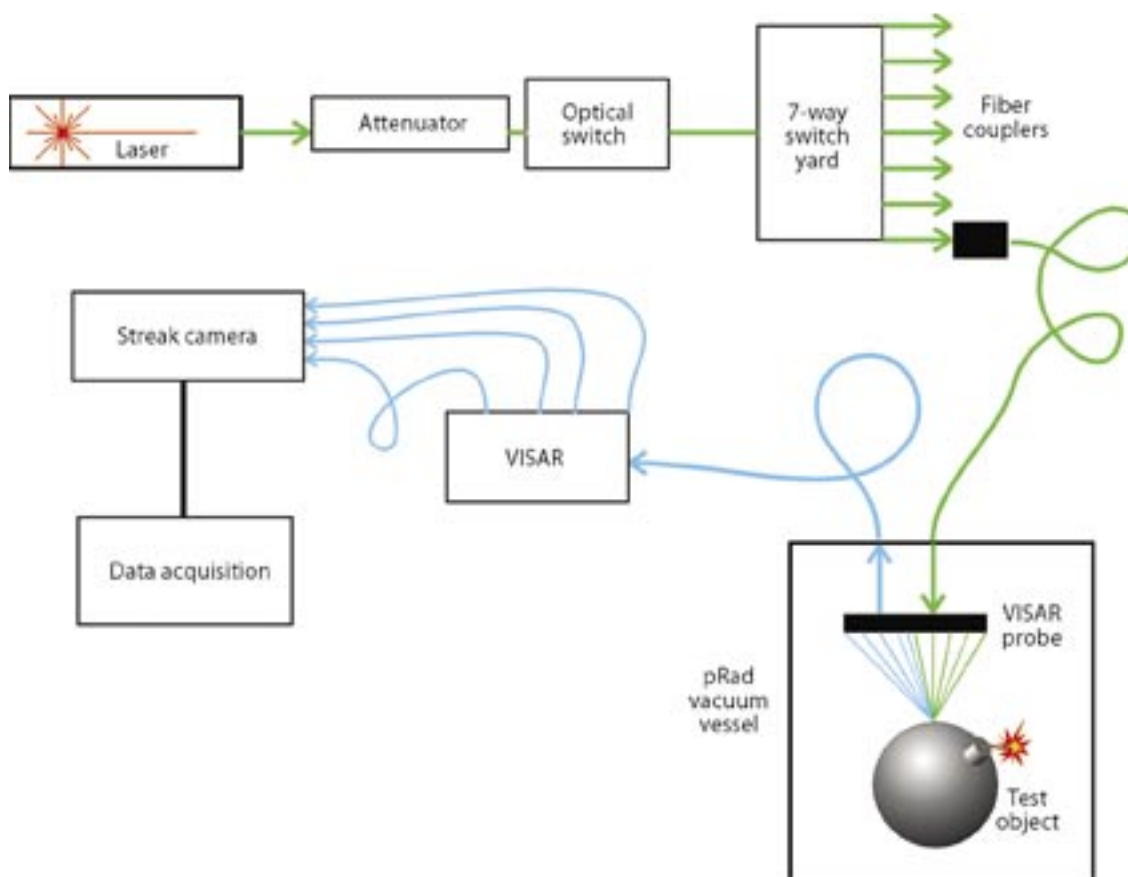


Figure 3. Schematic of the VISAR measurement apparatus, as used for pRad.

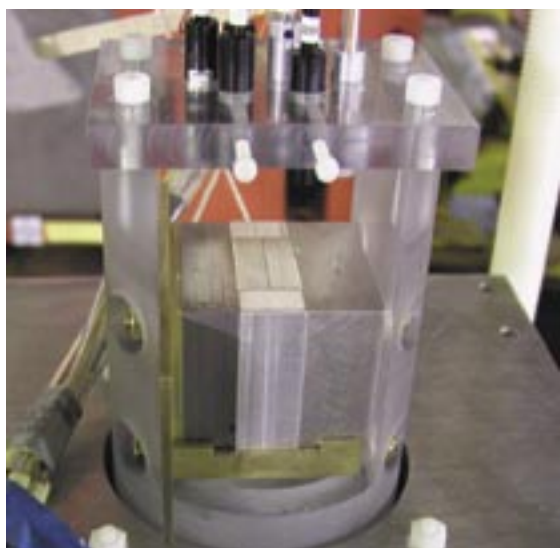


Figure 4. Seven VISAR probes aligned onto a pRad experiment. The black and metallic cylinders held by the upper Lucite block are the probes. Seven points of green light on the surface of the test object are from the alignment laser light coming through the probes; scattered light from each spot is gathered by the respective probe to be analyzed by the VISAR interferometer.

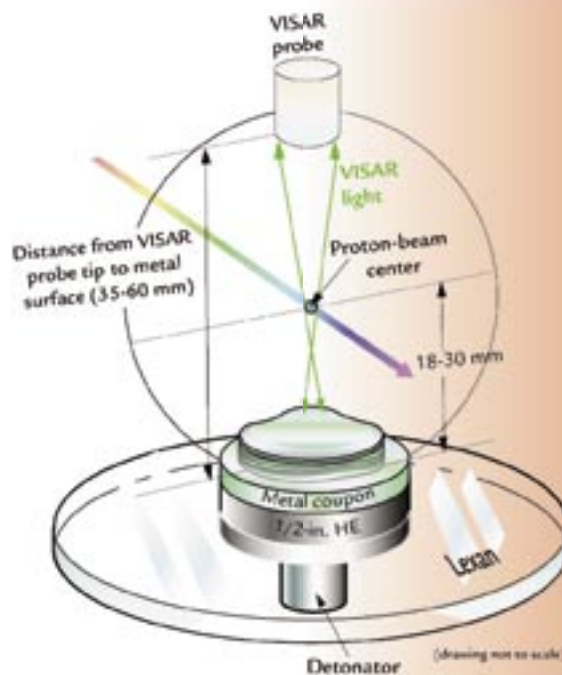


Figure 5. Diagram of high-explosive spall/damage experiment. The composition and thickness of the metal cylinder, or coupon, varies for different experiments.

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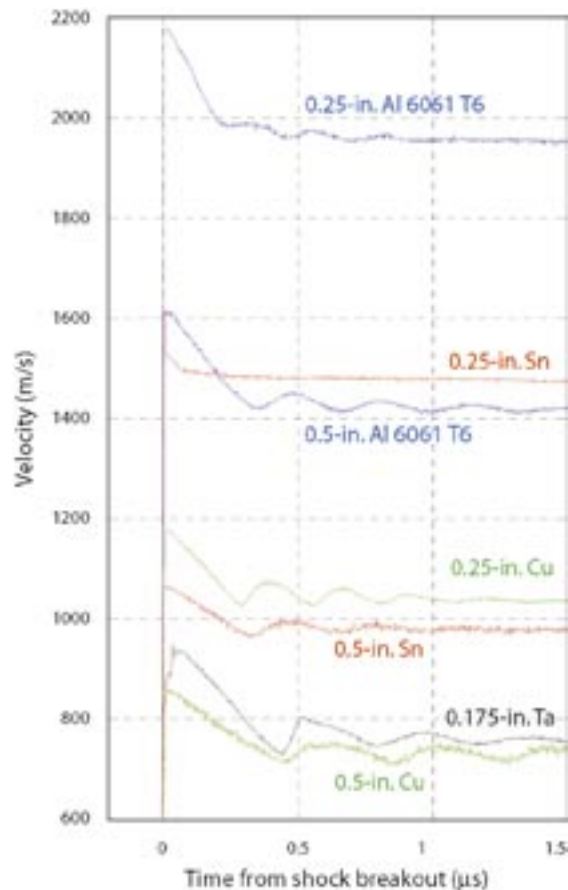


Figure 6. VISAR measurements of surface velocity from several pRad experiments. Results are shown for differing thicknesses of 6061-T6 aluminum (blue), tin (red), copper (green), and tantalum (black). Zero time is adjusted for breakout at the same time for each experiment. The entire time scale of the graph is $< 3 \mu\text{s}$, the typical spacing between pRad images.

References

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Acknowledgment

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Conclusion

A VISAR system has been installed in pRad to measure the surface velocity of test objects during dynamic experiments. The system has been upgraded to allow measurements of up to seven points on the surface simultaneously. The system has been used for over a dozen experiments in the last year at pRad. The pRad VISAR is ready to be available upon request to users at pRad to supplement the information learned in their experiments.

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